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Comparative Density and Strength of Cement Mortar

Civil Engineering

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COMPARATIVE DENSITY AND STRENGTH OF CEMENT MORTAR

BY

THOMAS GROVER LOWRY

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

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PRESENTED, JUNE, 1908

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THOMAS GROVER LOWRY

ENTITLED COMPARATIVE DENSITY AND STRENGTH OF CEMENT MORTAR

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

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COMPARATIVE DENSITY AND STRENGTH OF CEMENT MORTAR

INTRODUCTION

Experiments, made at Little Falls, N. J. in 1901, upon the density and strength of concrete beams, mixed in various proportions by weight, indicate that the strength of concrete varies with the density of the specimen and with the percentage of cement. With the same percentage of cement in a given volume of concrete, the densest mixture irrespective of the relative proportions of sand and cement was the strongest.

With the foregoing law established it would be possible to obtain a mixture of maximum density by making the volumetric or density tests and to assume that such a mixture would give maximum strength.

Following the same line of investigation as in the experiments mentioned above,

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a series of tests extending over a period of two years was carried on at Jerome Park N. Y., under the authority of the Aqueduct Commission of the City of New York. A complete description of these tests is given in Vol. 3, No. 3 Proceedings of the American Society of Civil Engineers in an article written by W. B. Fuller and S. E. Thompson. Hereafter reference will be made frequently to Fuller's methods and Fuller's conclusions as given in that article.

Among these conclusions are the following.

1.- "The best mixture of cement and aggregate has a mechanical analysis curve resembling a parabola, which is a combination of a curve approaching an ellipse for the sand portion and a tangent straight line for the stone portion. The ellipse runs to a diameter of one tenth of the diameter of the maximum size of stone and the stone from this point is uniformly graded."

2.- "The strength and density of concrete is affected but slightly,

if at all, by decreasing the quantity of the medium size stone of the aggregate and increasing the quantity of the coarsest stone. An excess of stone of medium size, on the other hand, appreciably decreases the density and strength of the concrete."

3.- "The substitution of cement for fine sand does not affect the density of the mixture, but increases the strength, although in a slightly smaller ratio than the increase in the ratio of cement."

The above conclusions were made from tests on concrete but it is reasonable to suppose that the same principles would hold for mortar since they were supported for concrete in which the maximum size was ½ inch as well as in that which had 2¼ inch stone for the maximum size. M. R. Feret, in his tests upon mortar has made some conclusions which make the foregoing assumption at least probable.

1.- Coarse sand produces stronger and usually more impervious mortar than fine sand.

2.- Fine sand requires more water than coarse sand to produce a mortar of like consistency and consequently the mortar is less dense.

3.- Mixtures of fine and course sand produce stronger mortar than either material alone.

4.- Sands for maximum density are composed of a mixture of fine and coarse grains with no intermediate grains.

DESCRIPTION

A number of tests were made by the writer for the purpose of testing the applicability of Fuller's conclusions to portland cement mortar. Several mixtures of cement and differently graded sand were tested for density by measuring the volume resulting from a definite weight of materials, and a comparison was made with the tensile and the compressive strengths of briquettes and cubes made from similar mixtures.

A definite combination of sizes was used in each mixture and a constant maximum size of sand and per centage of cement were maintained throughout the tests. The percentage of water required to obtain a medium wet consistency was determined in the volumetric or density tests and water was used in the same ratio when mixing up the mortar for the cubes and briquettes.

The sand portion of the mixtures investigated was composed of various sized particles from the finest to the maximum size used. The percentages of the various sizes were determined graphically from the curves plotted on Plate I, p/29, which are called "Mechanical Analysis Curves."

Mechanical Analysis.- Mechanical analysis consists of separating a sand into the various sized particles of which it is composed. A graphical method of representing a mechanical analysis is to plot a curve which shows the relative size of the particles. The abscissae of the curves are the sizes of the particles and the ordinates are the percentages of the total weight finer than the sizes represented by the corresponding abscissae.

The practical uses of a mechanical analysis curve for sand is to show graphically the relative sizes of the particles in any sand and thus show what sizes should be added or taken away

to improve the mixture. It also shows what proportions of two sands should be used to obtain the best mortar.

Materials.- Cement.- Chicago A-A cement from a single sack yielding the results below was used throughout.

TESTS OF CHICAGO A-A CEMENT

Specific Gravity = 3.12

Tensile Strength		Mechanical Analysis		
Age in days	Pounds per square inch	Sieve	Per cent. Retained	Per cent Passing
1	290	60	0.0	100
7	600	74	1.5	98.5
28	750	100	4.4	95.6
		200	20.0	80.0
		Pan	80.0	—

Sand.- Sand from the Wabash River was the only kind used. Sizes larger than 0.2 inch were screened out and a mechanical analysis for the remaining material was made The percentage of the various sizes is given in the second column of Table IIII, and the curve itself with cement added in the ratio of

1:3 is shown in Curve 3 on Plate II

Character of Sand. - The sand was uniform in structure. The specific gravity was determined for several different sets of sizes as well as for the natural run and was found to be 2.66 in each case.

Screening Sand. - Standard sieves were used to screen the sand into thirteen sizes. A motor-driven sifting machine made practicable the sifting of the large amount of sand needed. By running the machine a given length of time and using the same amount of sand in each charge uniform sifting was obtained.

SIZES OF SIEVES

Commercial No. of Sieves	Dia. of Particle Passing	Commercial No. of Sieves	Dia. of Particle Passing
5	0.1600	40	0.0160
8	0.1000	60	0.0120
10	0.0750	74	0.0071
16	0.0430	100	0.0058
20	0.0340	150	0.0036
30	0.0200	200	0.0027

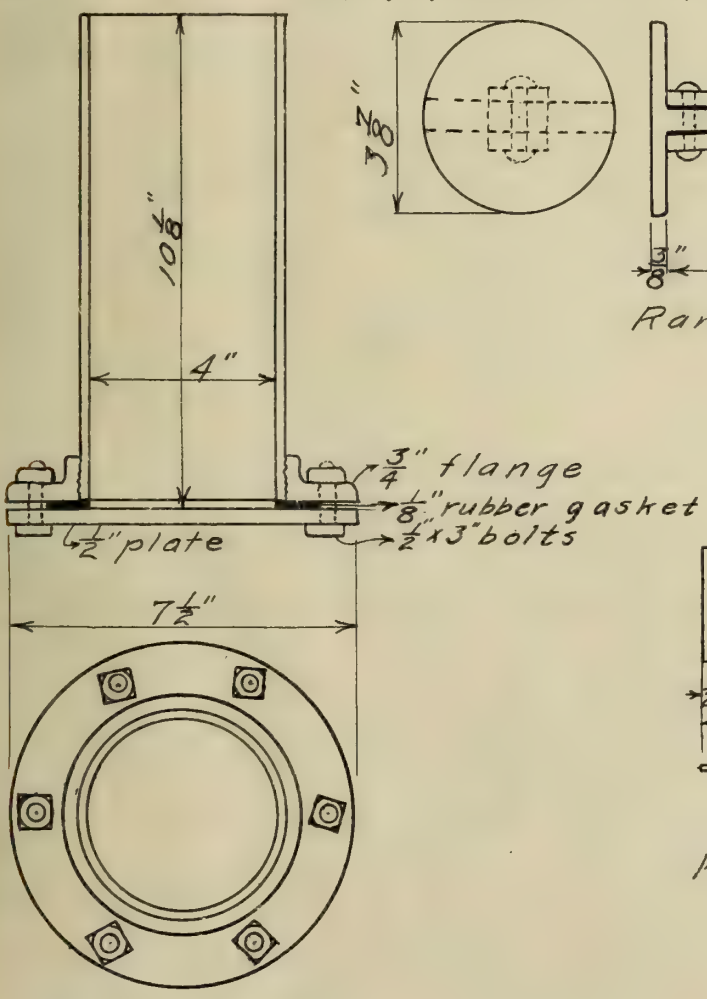
Note. - Another sieve having no commercial number was used, which allowed particles 0.2 inch in diameter to pass.

In the tables, P 200 means passing the 200 sieve and R 200, R 150 etc. means retained on No. 200, etc.

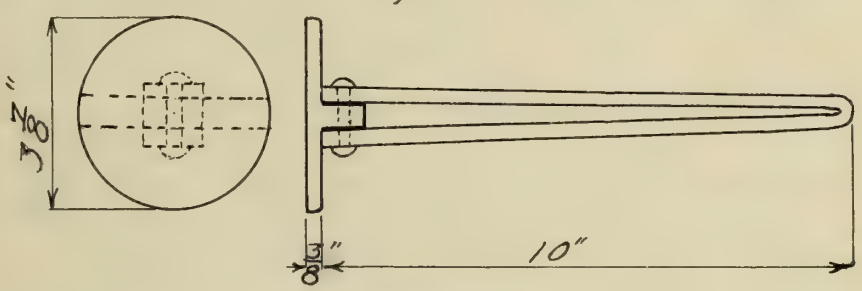
Volumetric Tests.

A volumetric test is the determination of the actual volume or density of a material. For each set of briquettes and cubes a volumetric test of the mixture used was made. The tests of density were made according to the methods used in the Jerome Park experiments.

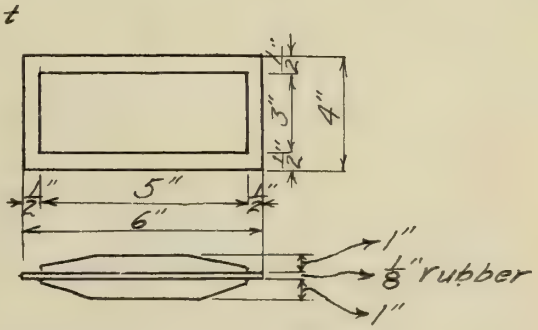
APPARATUS.- Fig. 1.



Cylinder



Rammer



Rubber Brush

Weighing.- The Harvey balance was used to weigh out the sand and cement for the volumetric tests. The schedule of weights was made up so that each weight included the weight of all the finer sizes. At the last the full amount of cement was added. The cement was weighed directly from the sack, it being assumed that it conformed to the mechanical analysis given on page 7.

Mixing.- Having the course sand at the bottom of the heap and the cement at the top it was not difficult to mix the sand and cement thoroughly with a trowel.

Owing to the variation in the sizes of the sand no definite per centage of water could be selected in advance for each mix. The water, therefore, was added by trial until a mortar of mushy consistency was obtained. Record was kept of the exact amount of water required to obtain the desired consistency, so that the quantity of water in the mixture could be eventually determined.

as soon as the water was thoroughly mixed with the cement and sand, the mortar was transferred from the mixing pan to the cylinder. Care was taken that all of the mortar should reach the cylinder, the pan being scraped clean of all cement, water and fine sand with a rubber brush. The weights of the tools and mixing tray before and after mixing were recorded and the amount of mortar adhering was obtained. This process was necessary in order that the net water, cement and sand in the mix as set might be computed.

Ramming. - In ramming the mortar into the cylinder care was taken to hasten settling by placing the mixture in two well-rammed layers two or three inches deep. The rammer used was a cast iron disk with a strap-iron handle and is shown in Figure 1. on page 9.

It was found that with a four-inch cylinder, the surplus water which

resulted from the trial mix could be removed after twenty minutes by pouring as the surface of the mortar was not disturbed by so doing.

The measurement of the volume of the mortar in the cylinder was made by taking the depth of the top of the mortar from the top of the cylinder. The cylinder was carefully calibrated and the calibration curve was found to be so near to a straight line that no appreciable error could result by considering the volume proportional to the depth. The results were tabulated and computed by the Fuller method.

Descriptions of Curves

All the curves (see p 29) are for mixtures of sand and cement in proportions of 3:1 The curves are coincident at the points ($x=0, y=13$) and ($x=0.2$ $y=100$)

Curve No. 1. – This curve was chosen to obtain an ellipse which should approach a tangent straight line at a point one tenth the maximum size

and to pass through the point ($x = 0.0027, y = 20$) A large amount of the clay like sand which passed the 0.0027 (200) sieve was undesirable. By making the ordinate at 0.0027 approximately 20 o/o, the cement took the place of the sand passing the 200 sieve.

Using zero co-ordinates on the mechanical analysis curve the equation for an ellipse is $y - y_1 = \frac{b}{a}\sqrt{2ax - x^2}$. By assuming $a = 0.072$ and $\frac{b}{a} = 350$, an ellipse was obtained which fulfilled the conditions when it was shifted upwards along the vertical axis until the starting point had the co-ordinates ($x = 0$, $y = 13$).

By subtracting the value of one ordinate from the next succeeding one the percentage of material retained on the sieve corresponding to the first ordinate was found. By tabulating these percentages opposite the corresponding size of sand a table showing the relative amounts of cement and sand to be used was obtained. Remembering that the mechanical analysis of the cement gave 80 o/o as passing the 200 sieve and that the

mortar was 1:3, it is easily seen that the per centage of sand in the mortar passing the 200 sieve is the difference between the ordinate on the curve at abscissa 0.0027 and $\frac{1}{4} \times 80$ or 20 o/o. Likewise for the amount of cement retained on the No. 200 sieve there is 1 o/o of the total mixture, for No. 150, 2 o/o; for No 100, 0.8 o/o and for No. 74, 1.2 o/o. These values are the same for all of the curves.

Curve No. 2. – The general equation for a parabola is $y^2 = px$. To make the curve pass through the points ($x = 0$, $y = 13$) and ($x = 0.2$, $y = 100$) the equation becomes

$$y - 13 = 87 \sqrt{\frac{x}{.2}}$$

Curve No 3. – Natural sand. – A mechanical analysis of the Wabash sand was made and a mechanical analysis curve plotted for a mixture of this sand with cement in the ratio of 3 to 1. The percentages obtained in the analysis of the sand were multiplied by .75, this being the part of the total which consisted of sand. By adding the results to the per centages of cement for 1:3 mortar ordinates for the curve

were obtained and plotted.

Curve No. 4. — This curve follows curve No. 3 up to size 0.012 (No. 60) from which point it runs horizontal up to size 0.043 (No. 16) - that is, the intervening sizes are omitted. From size 0.043 (No. 16) up to the maximum size the sand is uniformly graded. The table was compiled scaling the values from a curve of large size.

Curve No. 5. — This curve omits all of the sand finer than size 0.016 (No. 40), but does not omit size No 40. From size No. 40 up to the maximum size the sand is uniformly graded.

Curve No. 6. — The per centage of the larger sizes is slightly decreased by making the curve more nearly horizontal. The curve is coincident with Curve No. 3 up to size 0.007 (No. 74) from which point it passes up close to the parabola at ($x = .02$, $y = 38$) and is uniformly graded from there up to the maximum size.

Tensile and Compressive Strengths.

Compression.- Two six inch cubes for compression tests were made for each curve. A batch of 17000 grams of cement and sand were weighed upon small platform scales according to the schedules tabulated. This mixture of cement and sand was thoroughly trowelled together until an evenly colored mixture was obtained and then the same percentage of water was added as was used for the volumetric test. When this mortar was trowelled to an even consistency it was placed in the cube forms and rammed in two layers. The tops of the cubes were trowelled smooth and were watered every day for a week. At the end of the seven days the cubes were taken from the forms and imbedded in damp sand for three weeks, at the end of which time they were

removed to be tested. The cubes were capped with plaster of paris to obtain uniform bearing over the entire surface exposed to the bearing plate. The cubes were broken in a 100,000 pound Olsen testing machine, which applied the load at about 5000 pounds per minute.

Briquettes. – Besides the cubes six standard briquettes were made from the same mix. Hand molding was used and uniformity for the various tests was kept in view. The briquettes were kept beneath a damp cloth for twenty four hours and were then immersed in flowing water until they were tested at the age of twenty eight days in a Riehle briquette testing machine.

TABLE II

SCHEDULE OF WEIGHTS

FOR THE

ELLIPSE - CURVE No 1

Sieve	Per Cent	Per cent. of		For Volumetric Test		For Cubes and Briquettes	
		Cement	Sand	Cement gms.	Sand gms.	Cement gms.	Sand gms.
P 200	20.0	20.0		625		4250	
R 200	1.0	1.0					
R 150	2.0	2.0					
" 100	0.8	0.8					
" 74	3.1	1.2	1.9		47.5		323
" 60	1.7		1.7		42.5		289
" 40	1.4		1.4		35.0		238
" 30	5.6		5.6		140.0		952
" 20	3.6		3.6		90.0		612
" 16	12.3		12.3		307.5		2091
" 10	9.5		9.5		237.5		1615
" 8	23.3		23.3		582.5		3961
" 5	15.7		15.7		392.5		2669
Totals	100.0	25.0	75.0	625	1875.0	4250	12750
		100.0		2500		17000	

TABLE III

SCHEDULE OF WEIGHTS FOR CURVE No 2

Sieve	Per Cent.	Per Cent. of Cement	Per Cent. of Sand	For Volumetric Test: Cement gms	For Volumetric Test: Sand gms	For Cubes and Briquettes: Cement gms.	For Cubes and Briquettes: Sand gms.
P200	22.6	20.0	2.6	625	65.0	4250	442.
R200	2.1	1.0	1.1		27.5		187.
" 150	3.1	2.0	1.1		27.5		187
" 100	1.6	0.8	0.8		20.0		136
" 74	4.8	1.2	3.6		90.0		612
" 60	3.3		3.3		82.5		563
" 40	3.0		3.3		75.0		510
" 30	8.3		8.3		207.5		1410
" 20	4.5		4.5		112.5		765
" 16	12.9		12.9		322.5		2193
" 10	8.3		8.3		207.5		1410
" 8	16.7		16.7		417.5		2839
" 5	8.8		8.8		220.0		1496
Totals	100.0	25.5	75.0	625	1875.0	4250	12750
		100.0		2500		17000	

TABLE III

SCHEDULE OF WEIGHTS FOR CURVE No 3

Sieve	Per Cent.	Per Cent. of		For Volumetric Test		For Cubes and Briquettes	
		Cement	Sand	Cement gms.	Sand gms.	Cement gms.	Sand gms
P200	1.0	20.0	0.75	625	18.7	4250	127
R200	0.1	1.0	0.07		1.8		12
" 150	0.6	2.0	0.45		11.3		76
" 100	2.0	0.8	1.50		37.4		255
" 74	2.1	1.2	1.57		39.2		267
" 60	10.1		7.57		189.2		1275
" 40	11.6		8.70		217.5		1470
" 30	19.5		14.64		366.2		2480
" 20	6.8		5.10		127.5		867
" 16	26.2		19.65		491.0		3330
" 10	7.4		5.55		138.8		944
" 8	8.9		6.67		166.8		1175
" 5	3.7		2.78		69.6		472
Totals	100.0	25.0	75.00	625	1875.0	4250	12750
		100.0		2500		17000	

TABLE IV

SCHEDULE OF WEIGHTS FOR CURVE Nº 4

Sieve	Per Cent.	Per Cent. of		For Volumetric Test		For Cubes and Briquettes	
		Cement	Sand	Cement gms.	Sand gms.	Cement gms.	Sand gms.
P200	20.74	20.0	0.74	625	18.5	4250	126.0
R 200	1.10	1.0	0.1		2.5		17.0
" 150	2.49	2.0	0.49		12.2		83.0
" 100	2.30	0.8	1.50		37.5		255.0
" 74	2.79	1.2	1.59		39.8		270.0
" 60	.00		.00		00.0		00.0
" 40	00		.00		000		00.0
" 30	00		.00		00.0		00.0
" 20	00		.00		00.0		00.0
" 16	14.30		14.30		357.0		2426.0
" 10	11.30		11.30		282.0		1913.0
" 8	27.00		27.00		675.5		4580.0
" 5	18.00		18.00		4500		3080.0
Totals	100.0	25.00	75.00	625	1875.0	4250	12750
		100.0		2500		17000	

TABLE V

SCHEDULE OF WEIGHTS FOR CURVE No 5

Sieve	Per Cent.	Per Cent. of		For Volumetric Test		For Cubes and Briquettes	
		Cement	Sand	Cement gms.	Sand gms.	Cement gms.	Sand gms.
P 200	20.0	20.0	0.0	625	0.0	4250	00
R 200	1.0	1.0	00		00		00
" 150	2.0	2.0	00		00		00
" 100	0.8	0.8	00		00		00
" 74	1.2	1.2	00		00		00
" 60	0.0		0.0		0.0		00
" 40	1.5		1.5		37.5		255
" 30	5.9		5.9		147.5		1003
" 20	3.5		3.5		87.5		595
" 16	13.1		13.1		327.5		2227
" 10	10.3		10.3		257.5		1751
" 8	24.4		24.4		610.0		4148
" 5	16.3		16.3		407.5		2771
Totals	100.0	25.0	75.0	625.0	1875.0	4250	12750
		100.0		2500		17000	

TABLE VI

SCHEDULE OF WEIGHTS
FOR
CURVE No 6

Sieve	Per Cent	Percent of Cement	Percent of Sand	For Volumetric Test		For Cubes and Briquettes	
				Cement gms	Sand gms	Cement gms	Sand gms
P200	20.7	20.0	0.7	625	17.5	4250	119.
R200	1.1	1.0	0.1		2.5		17
"150	2.5	2.0	0.5		12.5		85
"100	2.3	0.8	1.5		37.5		255
" 74	4.4	1.2	3.2		80.0		544
" 60	3.3		3.3		82.5		561
" 40	3.7		3.7		92.5		629
" 30	5.0		5.0		125.0		850
" 20	3.0		3.0		75.0		510
" 16	11.6		11.6		290.0		1972
" 10	8.0		8.0		200.0		1360
" 8	20.6		20.6		515.0		3502
" 5	13.8		13.8		345.0		2346
Totals	100.0	25.0	75.0	625	1875.0	4250	12750
		100.0		2500		17000	

TABLE VIII

COMPOSITION, AND TENSILE AND COMPRESSIVE STRENGTHS OF CEMENT MORTAR MADE WITH DIFFERENTLY GRADED SAND

Proportions: 1:3. Materials: Chicago A-A Cement, Wabash sand-Max. size-.2 inch.

Curve No.	Wt. in grams of materials in 1 cu. cm. of mortar as set				Calculated Vol. in cu. cm. of material in 1 cu. cm. as set					Volume of voids in 1 cu. cm. as set.		
	Cement	Sand	Total dry mixture	Water	Cement	Sand	Total dry	Water	Total	* Cement	* Sand	Total
1	0.505	1.655	2.060	0.220	0.162	0.620	0.782	0.220	1.004	~~0.088~~	~~0.130~~	0.218
2	0.523	1.580	2.103	0.234	0.168	0.595	0.762	0.234	0.997	~~0.082~~	~~0.155~~	0.237
3	0.503	1.600	2.103	0.226	0.161	0.610	0.771	0.226	0.997	~~0.089~~	~~0.140~~	0.229
4	0.545	1.645	2.190	0.232	0.175	0.620	0.795	0.232	1.020	~~0.075~~	~~0.130~~	0.205
5	0.536	1.645	2.181	0.190	0.172	0.620	0.792	0.190	0.982	~~0.078~~	~~0.130~~	0.208
6	0.525	1.600	2.125	0.214	0.168	0.603	0.771	0.214	0.985	~~0.082~~	~~0.147~~	0.229

	Tensile Strength of Standard Briquettes					Compressive Strength of Six-inch Cubes				
	Age in Days	No. of Breaks	Pounds per square inch			Age in Days	No. of Breaks	Pounds per square inch		
			Maximum	Minimum	Average			Maximum	Minimum	Average
1	28	6	440	368	405	28	2	4880	4100	4490
2	"	"	490	430	452	"	"	4920	4300	4610
3	"	"	370	320	348	"	"	4550	4500	4525
4	"	"	475	400	435	"	"	5380	5250	5315
5	"	"	480	430	455	"	"	5080	4680	4880
6	"	"	475	425	439	"	"	4610	4350	4480

* Void - No data was taken by which values for the starred columns could be computed. The cancelled figures were computed through erroneous assumptions.

RESULTS AND CONCLUSIONS

In Table VIII are shown the results of the tests which have been described. The table shows the volume of the voids in the mortar as determined by the density tests. This volume was obtained by subtracting the absolute volume of the cement and sand from the volume of the mortar. The average values obtained for the tensile and compressive strengths of the different mortars are also given in the same table.

Inspection of the results shows that a wide enough range of tests was not attempted. Because of the small number of tests it would have been better had the curves been so chosen as to give a wider variation in the composition of the mortar. There is only five per cent. variation in the volume of the voids and ten per cent. variation in the compressive strength. This is not large enough for the relation between

the results from the curves to be well defined.

The tensile strength varies sufficiently; but since the Fuller conclusions do not mention tensile strength with density it is inadvisable with the few tests made to advance any opinion as to the relation of tensile strength to density.

A brief comparison, however, between Fuller's conclusions and the results obtained will be of interest.

Conclusion No. 1. as quoted at the beginning of this article is not verified. Curve No. 1 should give greater density and greater strength than any of the others if this ellipse is the ideal one for the material used. It is almost certain, however, that the ellipse used is not the ideal one since it runs so far below the parabola which according to Fuller's theory it should follow closely.

The results of Curve No. 4 agree with conclusion No. 2 that the density and strength is not decreased by the decrease in medium sized particles.

The results of Curve No. 5 are also in accord with conclusion No 3 that the substitution of cement for fine sand increases the strength without greatly affecting the density.

The results of Curve No. 6 have no value except in strengthening the general law that the density varies with the strength. The data on all six curves is to be construed as bearing out this general law. Curves No 2 and No. 3 do not give the desired results and are used only toward the same end as Curve No 6.

Remarks.- This investigation was not carried on long enough to give the necessary experience for insuring the desired uniformity in the consistency of the mortar and in the ramming of the briquettes and cubes. Better methods were

acquired as the tests proceeded and there is some assurance that the last three curves were tested accurately. However, two volumetric tests for each curve should have been made to eliminate any accidental errors. It would have been better also to have planned the tests so that the age of the specimens at testing could be ninety days instead of twenty-eight. The obstacles mentioned could be overcome easily for another year's work by preparing the materials some months in advance.

Though the number of tests was small, experience was gained which would lead to a better selection of mechanical analysis curves another time. More interesting results would be sure to follow and on account of the interest attendant upon such an investigation and the value of a confirmation of Fuller's theory, further work in the subject would be highly profitable.

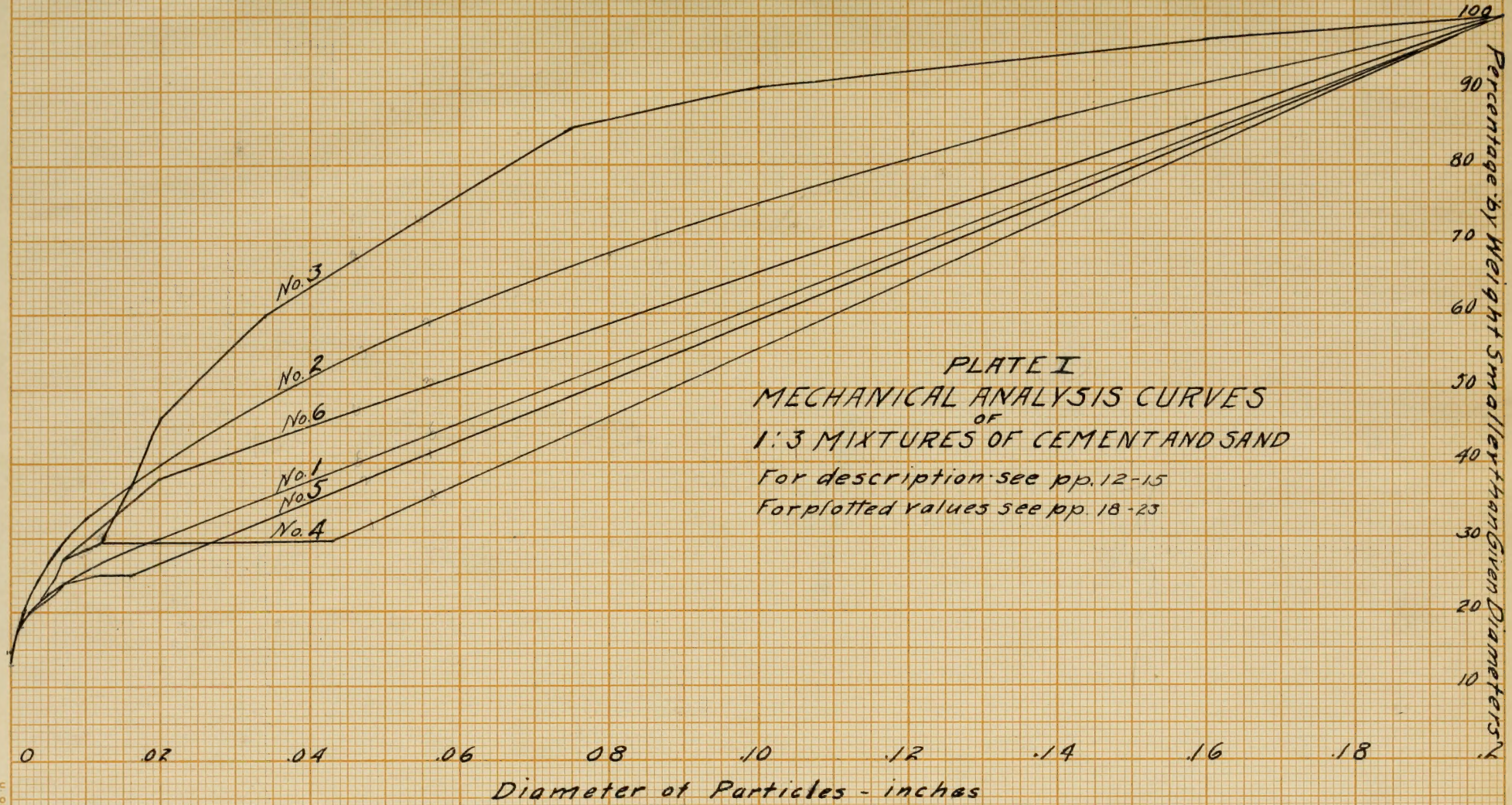


PLATE I

MECHANICAL ANALYSIS CURVES

OF

1:3 MIXTURES OF CEMENT AND SAND

For description see pp. 12-15

For plotted values see pp. 18-23

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